Lifetime of the CDF RunII Silicon

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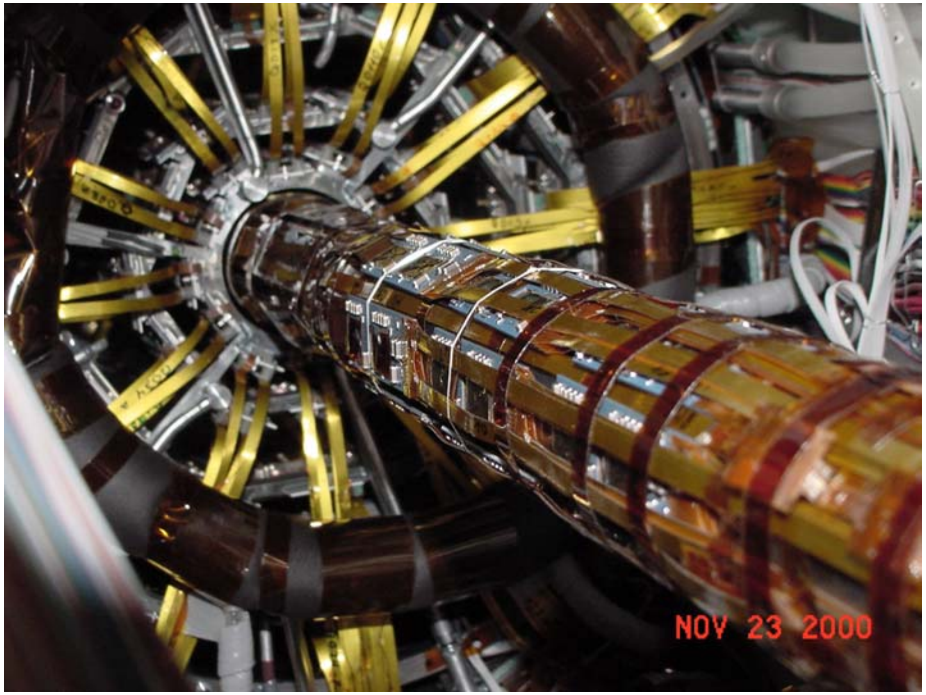
(with help from the CDF Radiation Monitoring and CDF Silicon Groups)

Outline

- Is the CDF silicon measurably damaged by radiation?
- Measuring the radiation field
  - Leakage current measurements
  - TLD measurements from the tracking volume
  - Depletion voltage measured from noise
- Lifetime of the Run IIa silicon
  - How does the silicon 'die'?
  - Signal
  - Noise
  - Degradation in b-tagging
- How long can it live?
- Conclusions

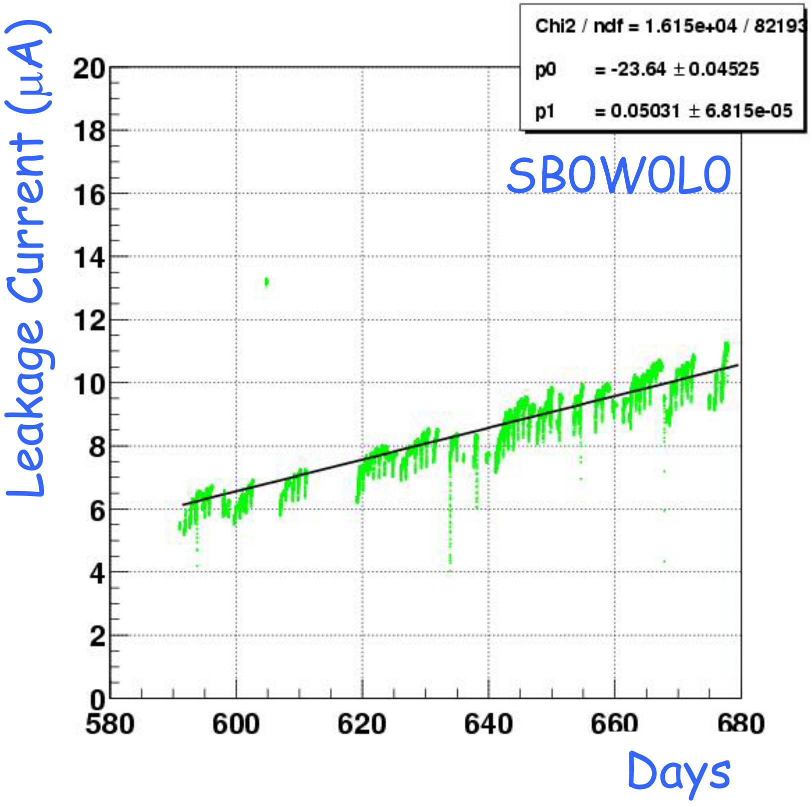


Is there measurable Radiation Damage at CDF?

(YES!)

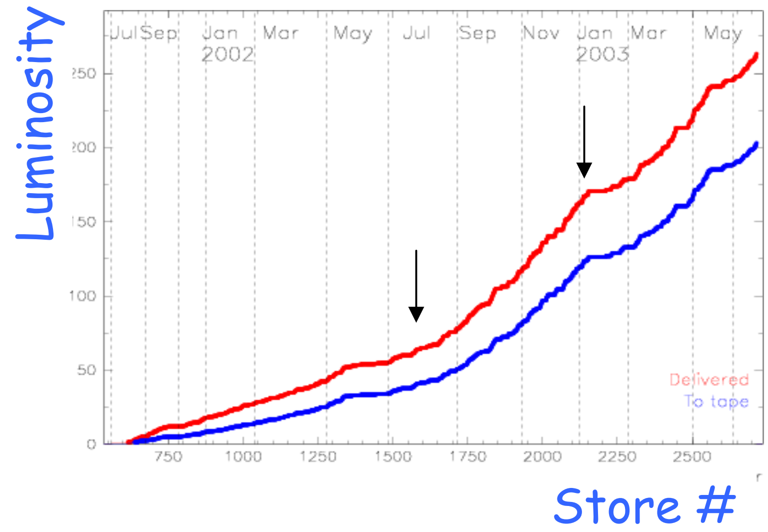
- Leakage current increases from surface and bulk damage
- Depletion voltage changes too…

We now have both radiation damaged silicon from a hadron collider environment, and models with which to compare



Leakage Current vs Integrated Luminosity

- 326 pb^{-1} delivered to CDF
- Current vs Luminosity well measured
  - measured for a stable run period
  - 100.7 pb^{-1}, from 8/15/02 to 1/21/03
  - Large variations seen module-to-module, especially for Micron sensors
  - Using (guard+bias)/volume



	ΔI/ ladder [μA]	RMS [μA]	Fluence 1 MeV n 1E12 /cm^2/fb^{-1}
Layer 00 narrow	4.89	1.57	30
Layer 00 wide	6.47	1.93	20
Layer 0	10	1.99	9.3
Layer 1	8.1	2.00	5.1
Layer 2	5.2	2.94	2.4
Layer 3	5.88	1.60	1.8
Layer 4	4.37	2.41	1.2

Run II Measurements vs. Run I Predictions

- Predictions from Run I vs. recent measurements
  - Currents measured in Run Ia and Run Ib average to be

    $I(24C,3cm) = 0.69 \pm 0.11\ nA/strip/pb^{-1}$
  - Using $\alpha = (3.0 \pm 1.0) \times 10^{-17} A/cm$ and scaling temperature, we predict

    $\Phi(1MeVn,L0) = (0.50 \pm 0.16) \times 10^{13}\ \ 1MeVn/cm^2/fb^{-1}$
  - Measurement from Run II is

    $\Phi(1MeVn,L0) = (0.93 \pm 0.26) \times 10^{13}\ \ 1MeVn/cm^2/fb^{-1}$

- Why are they different? Not sure, but…
  - CDF has been substantially reconfigured
  - Run II detector has much more material
  - Errors are still large; difference is only ~2σ
  - We are colder now, should probably use different alpha…

- What does this mean for the LHC?
  - Had been quoting CDF Run I measurements as check of simulations
  - LHC has more/different material

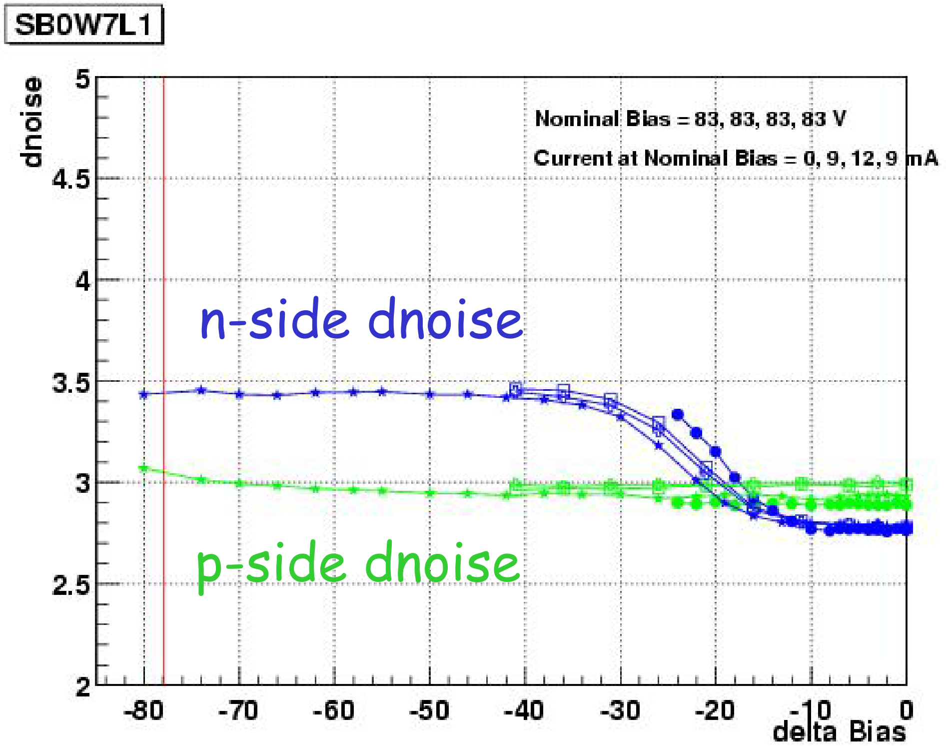
Noise as a measure of Depletion Voltage?

- Noise drops on n-side as Si is depleted
  - With double-sided silicon, might provide convenient monitor of Vdep
  - Operating voltages set to 20V (5V) above Vdep for Hamamatsu (Micron) Silicon
  - Can be automated and measured quickly, without collisions
  - "dnoise" = common mode subtracted noise

- Several measurements made:

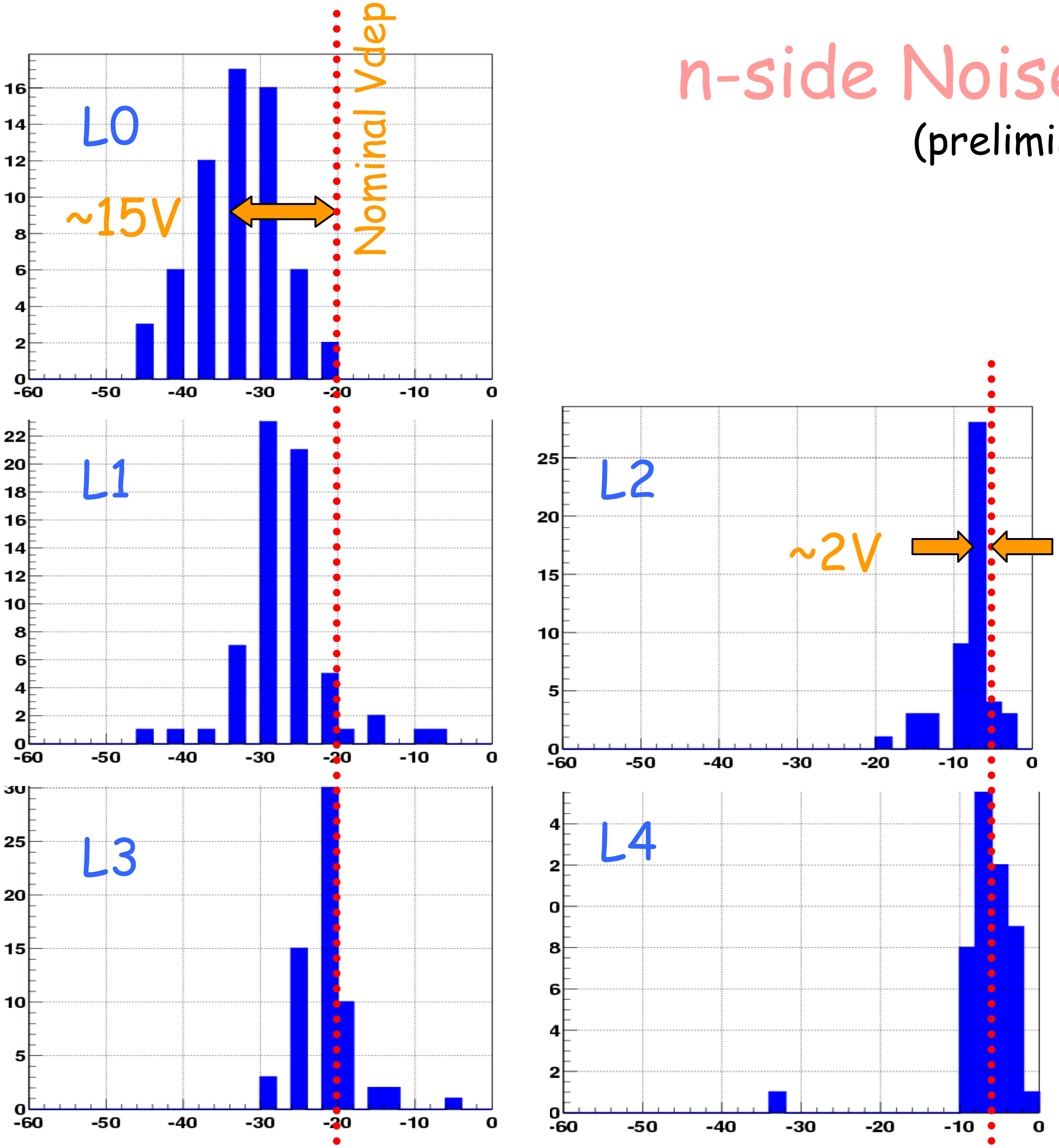
Mar	•	179 pb^{-1}
July	□	273 pb^{-1}
Aug	+	302 pb^{-1}
Sept	*	326 pb^{-1}

- Differences with CV and signal collection under study



n-side Noise vs Bias scans

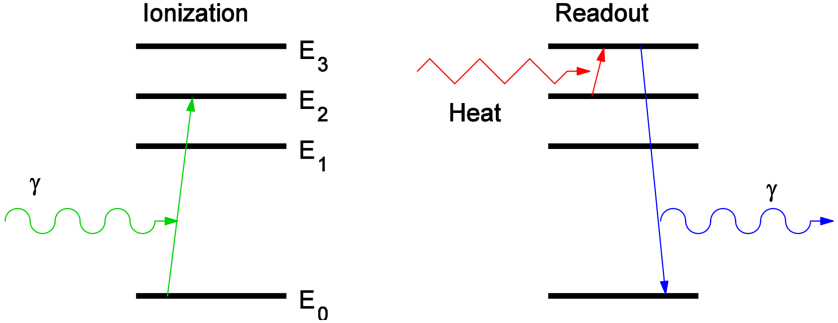
(preliminary results)

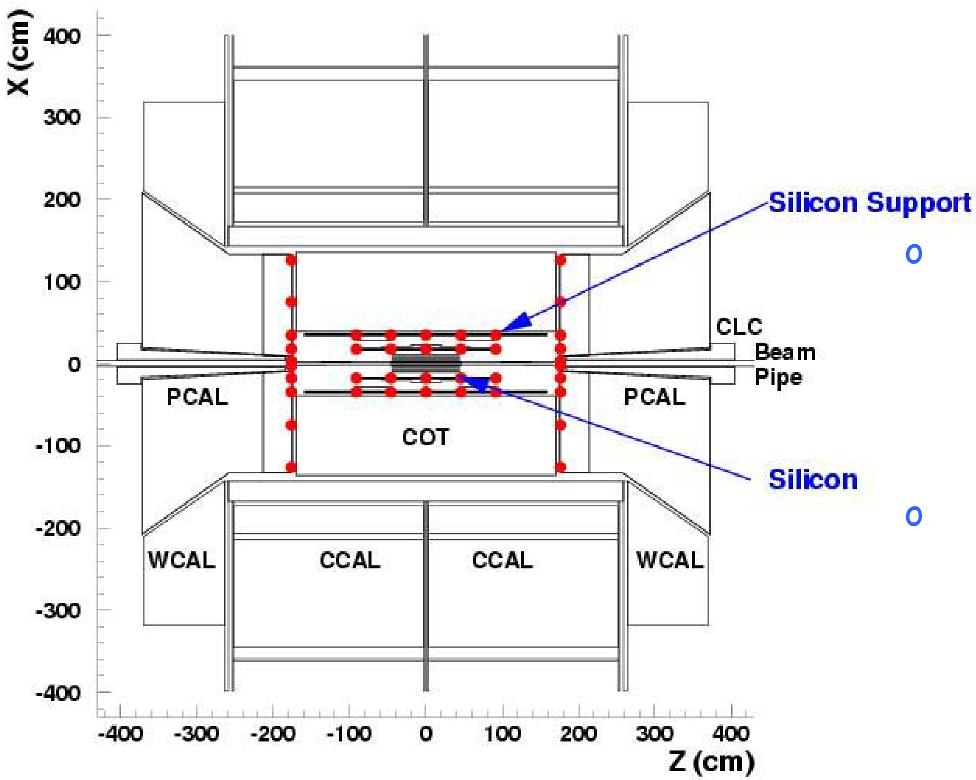


Hamamatsu　　　Micron

- Automate procedure for all layers and wedges
  - "Vdep" defined to be noise increase by >4%
  - Data for all layers of ISL, SVX
- Change in Vdep Evident
  - Nominal settings are vendor CV +20V (+5V) for Hamamatsu (Micron)
  - L0 shows average 15V decrease in Vdep
- Charge collection vs Vdep and L00 changes to be studied with signal scan

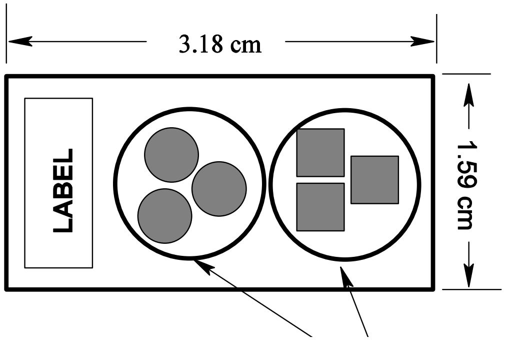
Measuring the Radiation Field: TLDs





- Thermo-luminescent Dosimeters (TLDs) have many advantages
  - Industry standard
  - Passive devices
  - Large range (mRad to 0.2 Mrad)
  - Excellent accuracy; 3% chip-to-chip variation, 1% reproducibiliy
- They also have some drawbacks
  - Require a lot of handing
  - Must be 'harvested' and read out
- TLDs with sensitivity to ionizing particles or neutrons are available.

Tracking Volume TLDs



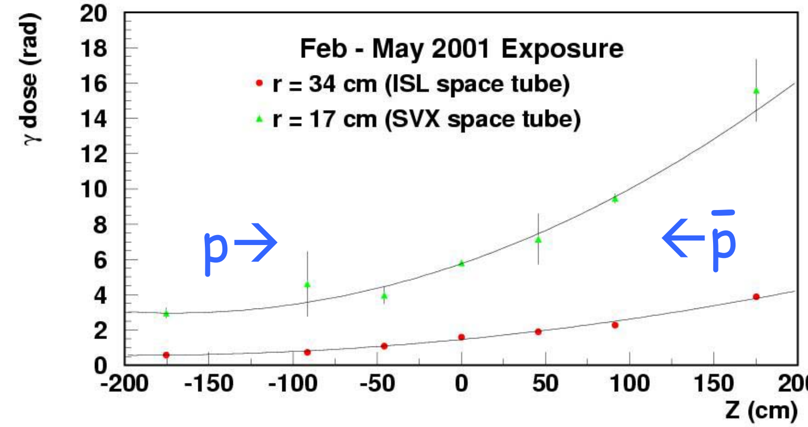
TLDs with ^{7}Li, ^{6}Li
Sensitive to γ, n

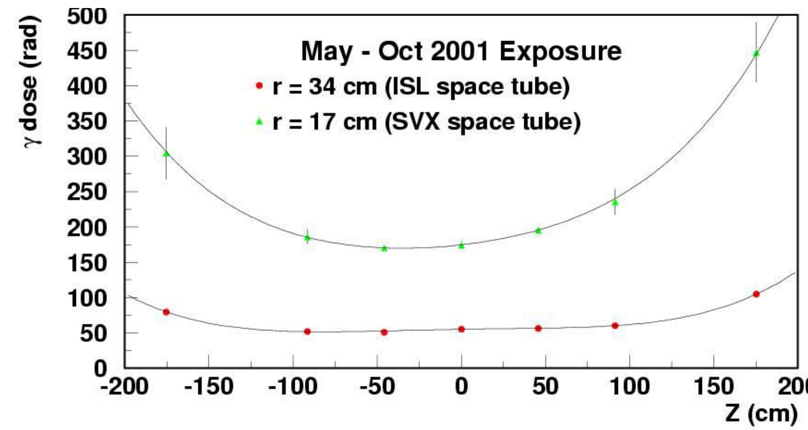
- TLD placement
  - TLD holders attached to kapton film and pulled into place like a 'clothesline'
  - Kapton leads fed through cables for silicon and drift chamber
  - Finding the ends can be difficult!

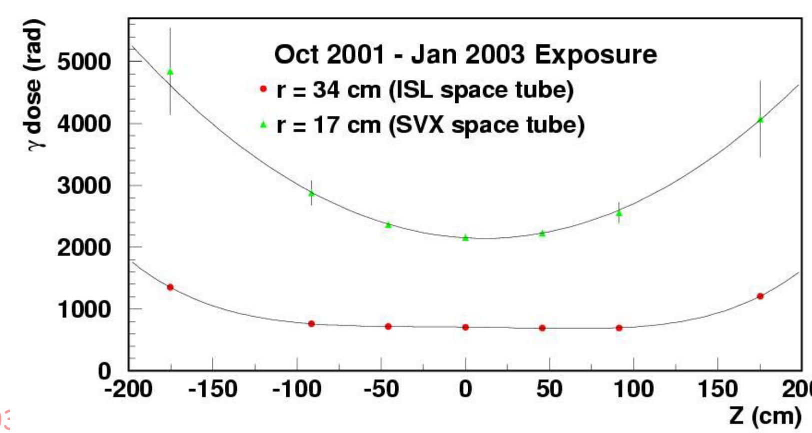
TLD data

- Data from three exposure periods
  - First one during loss-dominated period
  - Second period was a mix of losses and collisions
  - Final measurement almost all collisions

Period	Fraction of Dose From Losses (%)	Integrated Lum (pb^{-1})
Feb 01 - May 01	**80-90**	0.06
May 01 - Oct 01	**15-25**	10.7
Oct 01 - Jan 03	**5-10**	159

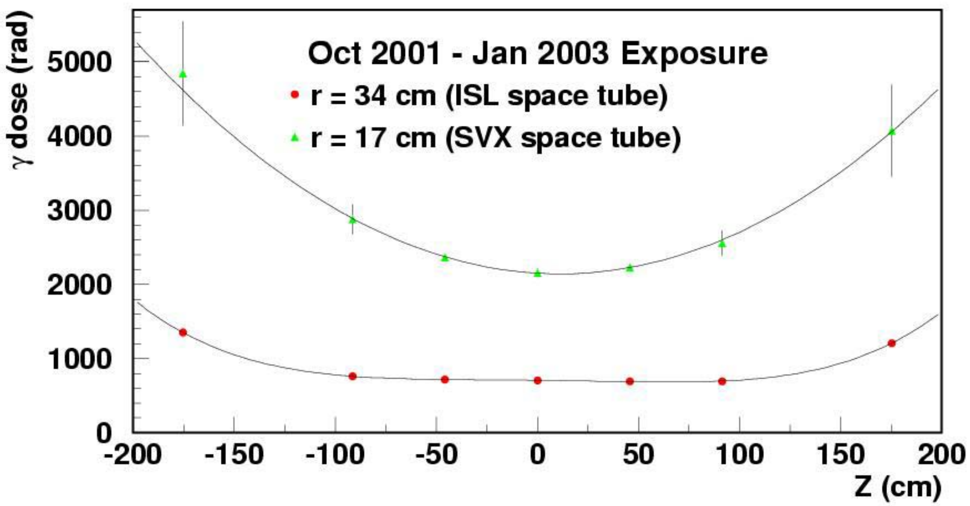


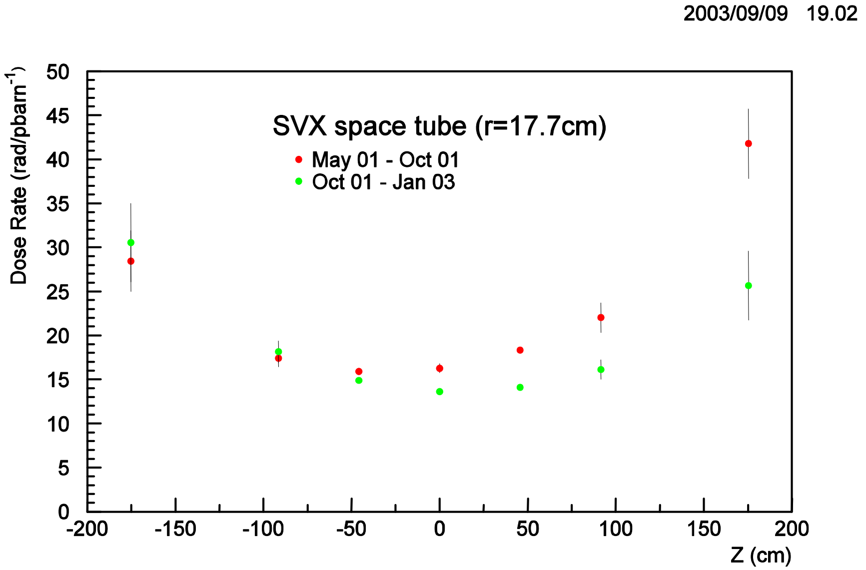


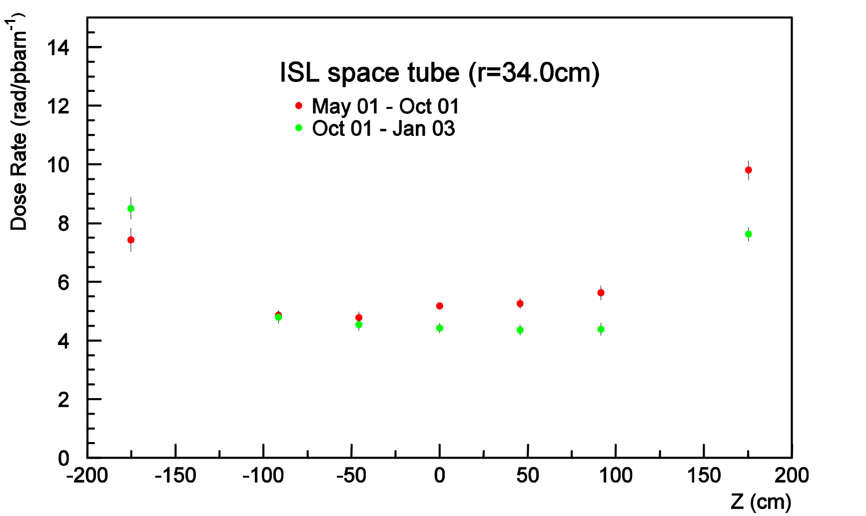


Latest TLD results

(preliminary)







- New measurement over long stable data taking period
- Last two measurements compare well
  - May 2001 to Oct 2001 (10.7 pb^{-1})
  - Oct 2001 to Jan 2003 (159 pb^{-1})
  - Raw ionizing radiation dose rates vs. z are very similar

"Death" of the Silicon; Modeling the S/N

- We expect that the inner silicon layers will eventually be unusable due to low S/N
  - Displaced track triggering will be good to S/N = 8.
  - B-tagging will be degraded at low S/N (in Run I, ε was lost below S/N ~6)

- Noise
  - Shot noise calculated from leakage current
  - Chip noise measured in controlled irradiations

- Signal
  - Double-sided AC-coupled silicon → voltage across readout caps
  - ~170V maximum depletion, from burn-in (180V) and other concerns
  - Axial strips are on p-side; can't get axial info while underdepleted
  - Depletion voltage estimates are therefore critical
  - We assume full charge collection throughout Run II

Noise Model for CDF

- Shot noise
  - Shot noise (108 ns int time) is given by

    $Q_{shot} = 900e^- \times \mathrm{sqrt}(I(\mu A))$

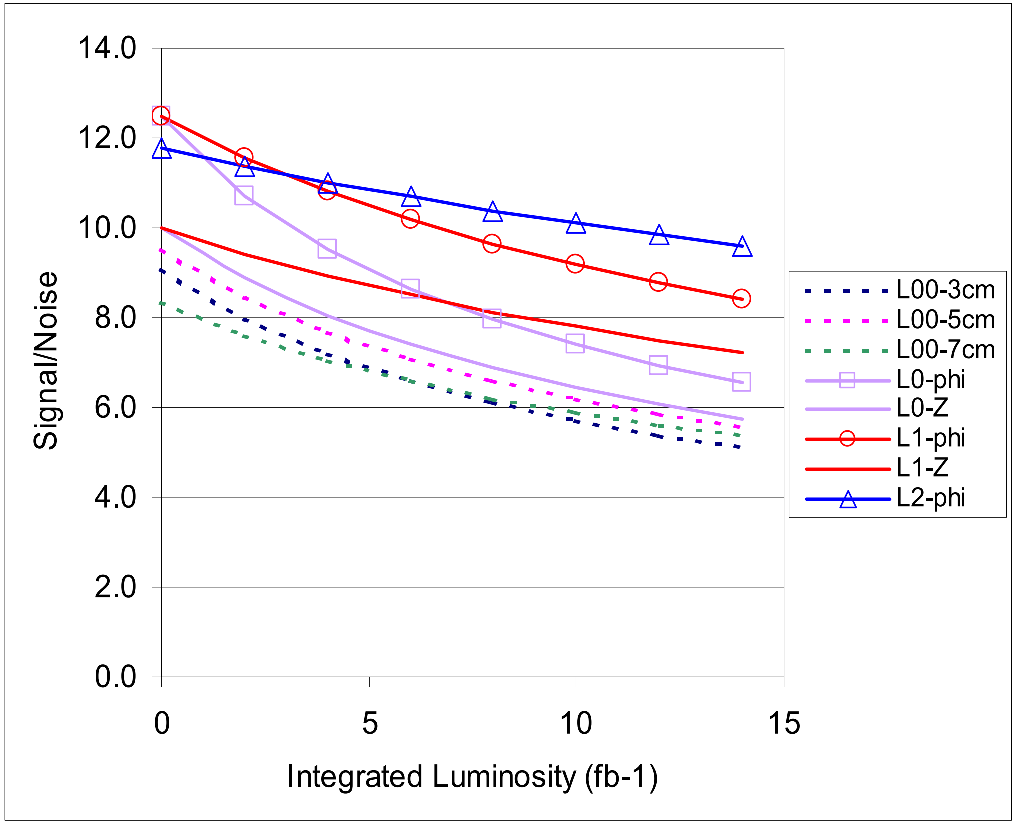
    $I_{L0} = 0.39\ nA/strip/pb^{-1}$
  - Radial scaling is estimated by using the TLD central data ($1/r^{1.590\pm0.008}$)
- Chip noise
  - Chip noise varied from 52 to 100 e^-/pF in 0-15 Mrad
  - Zero-load noise varied from 650 to 1100 e^- in 0-15 Mrad
- Inputs to model of leakage vs dose and initial noise now well measured

Sample values for 4 fb^{-1}:

Layer	Luminosity	Shot	Chip	Shot+Chip	S/N(20ke$^-$)	noise (ADC)
L0-phi	4	1125	1740	2072	9.7	3.5
L0-Z	4	1124	2175	2449	8.2	4.1
L1-phi	4	776	1665	1837	10.9	3.1
L1-Z	4	776	2081	2221	9.0	3.7

Noise Model; Results

- Noise degrades more steeply at first, then gradually
- S/N follows same trend (assuming full signal collection) and does not quite reach 6 for L0.



S/N begins near 12.5, and is expected to decline gradually

Depletion Voltage Model

We parameterize the Depletion Voltage in three parts (Hamburg model):

$\Delta N_{eff}(T,t,\Phi) = N_A + N_C + N_Y$

- **Short term annealing (N_A)**

  $N_A = \Phi_{eq}\sum_i g_{a,i}\exp(-k_{a,i}(T)t)$

  - Reduces N_Y (beneficial)
  - Time constant is a few days at 20 C

- **Stable component (N_c)**

  $N_c = N_{c0}(1-\exp(-c\Phi_{eq}))+g_c\Phi_{eq}$

  - Does not anneal (does not depend on time or temperature)
  - Partial donor removal (exponential or limited exponential)
  - Creation of acceptor sites (linear)

- **Long term reverse annealing (N_Y)**

  $N_Y = N_{Y,\infty}[1-1/(1+ N_{Y,\infty}k_Y(T)t)]$, $N_{Y,\infty}= g_Y\Phi_{eq}$

  - Strong temperature dependance
  - Can be significant long term; must cool Si

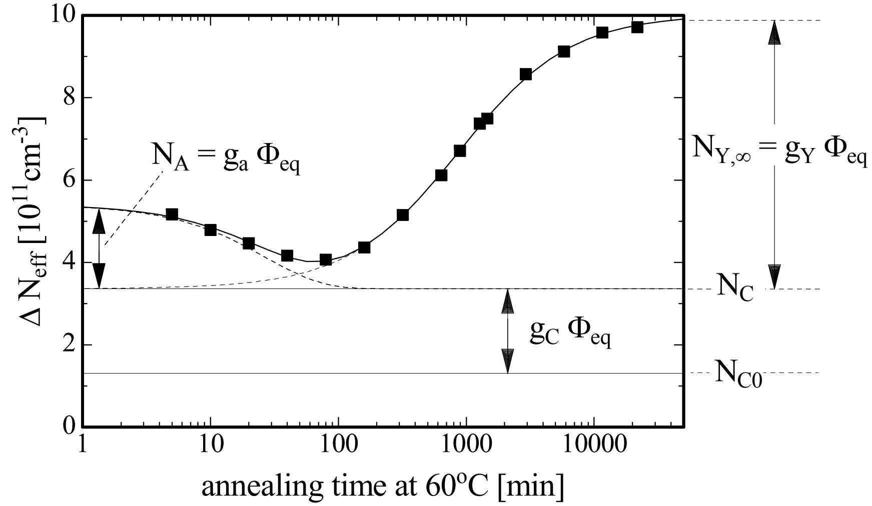


Fig.13: Annealing behaviour of the radiation induced change in the effective doping concentration ΔN_{eff} at 60°C.

Depletion Voltage Model – cont.

- Estimated overvoltage is included
  - We use a geometric model to estimate overvoltage [SCIPP 93/16];

    $$Vdep = Vplanar(1+(p/d)F(w/p))$$

    $$F(x) = -0.00111x^{-2} + 0.0586x^{-1} + 0.240 - 0.651x + 0.3555x^{2}$$

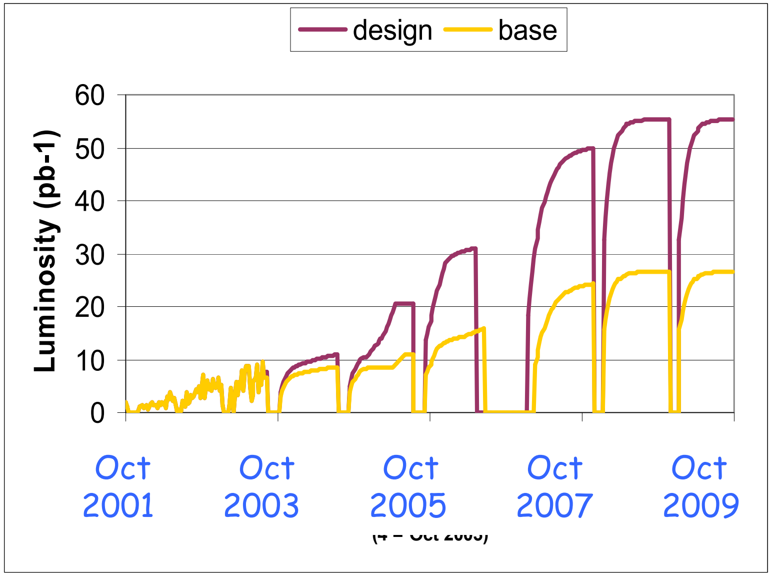
  - Provides a large multiplicative factor for CV (Vplanar), especially with narrow strips with wide pitches

- Long term (reverse) annealing is significant only at the end of the run

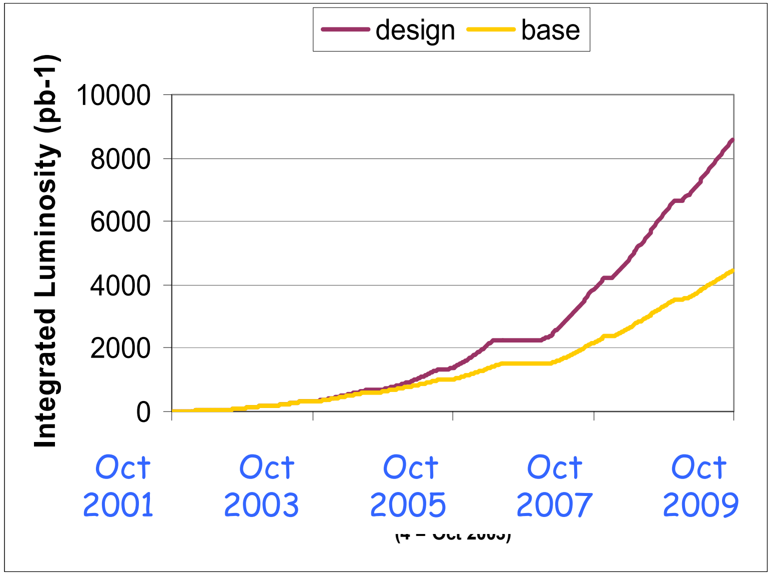
Parameter	Value
g_y [10^{-2}cm^{-1}]	4.6 ± 0.3
g_C [10^{-2}cm^{-1}]	1.77 ± 0.07
N_{C0} [10^{11}cm^{-3}]	5.0 ± 0.2
E_a [eV]	1.31 ± 0.04
c [10^{-13}cm^{2}]	2.0

Luminosity and Temperature Model

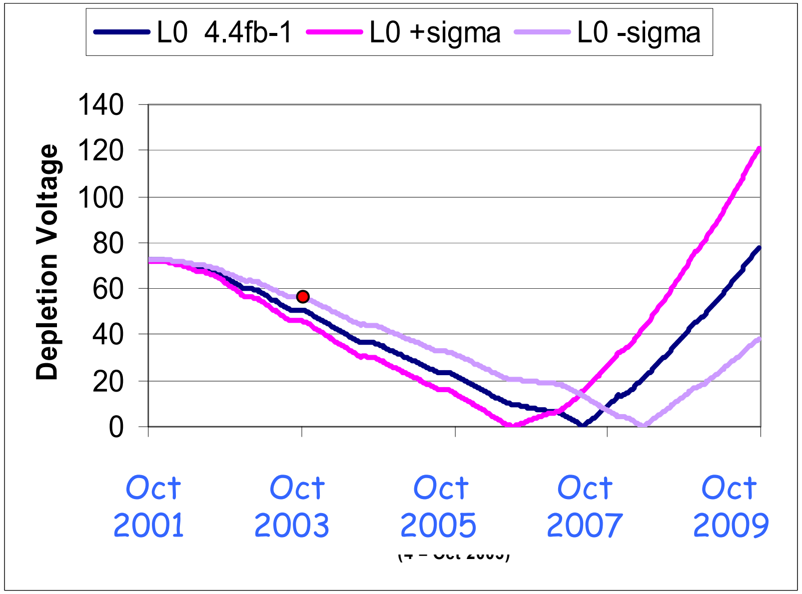
- Luminosity Model provided by the Tevatron Beams Division (July '03)
  - "Design" goal is ~6.5 fb^{-1} by mid 2008
  - "Base" goal is ~3.6 fb^{-1} by mid 2008
  - Expected shutdown periods included
  - Numbers are far more realistic than in the past… unfortunately also lower

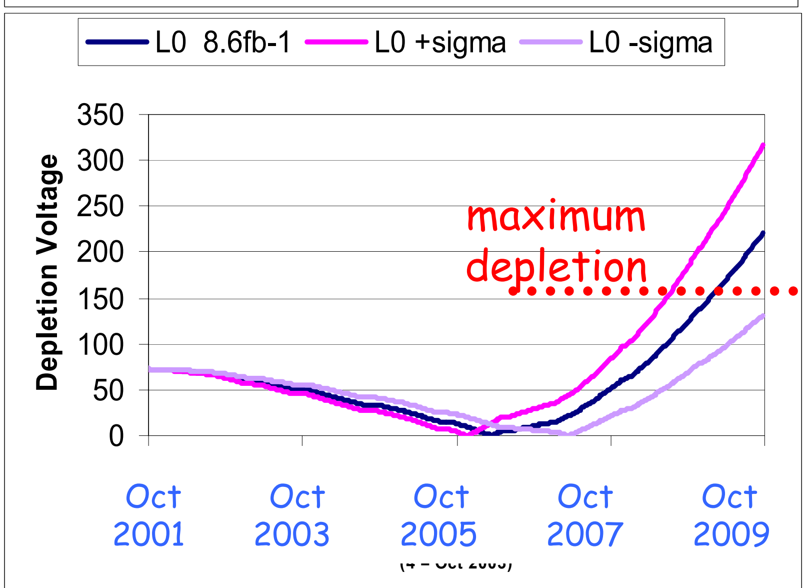


- Temperature modeled on current operating conditions
  - Chiller temperature is -6 °C
  - Warm parts of SVXII silicon are 12±2 °C cold, 16 °C warm (design temperature)
  - We can probably go colder



Depletion Voltage Results





- Results for "Base" luminosity
  - Indicates full depletion throughout RunIIa
  - Bands indicate approximate errors
  - Red dot is measurement from noise study

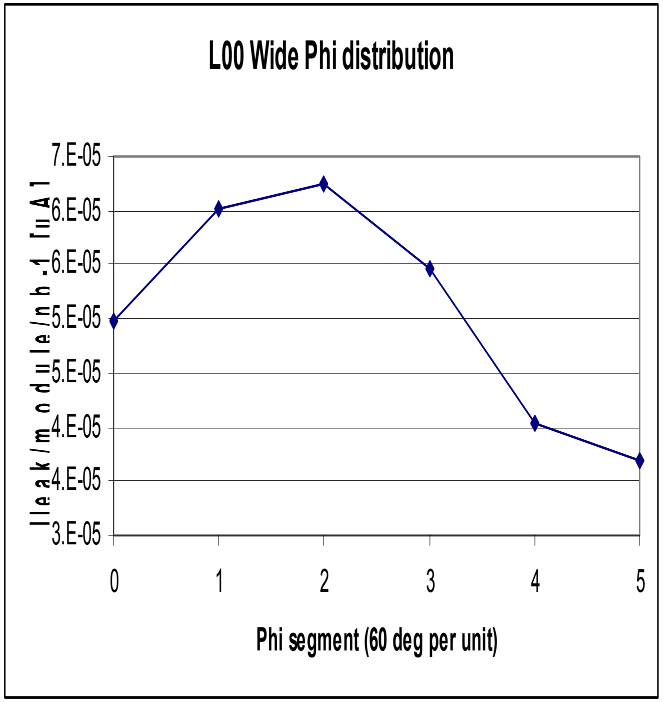
- Results for "Design" luminosity (assumes reasonable TeVatron improvement)
  - Silicon inner layer will die from radiation
  - Long term annealing becomes important
  - Errors are rather large, driven by large ladder to ladder RMS

An example “Real World” effect: Beam Offset

- The CDF detector and Tevatron beam are not perfectly co-axial
  Assuming a $1/r^{1.6}$ radial dependence, the top sensors of L00 receive ~50% more radiation than the bottom ones.

- Offset will be corrected in an upcoming shutdown

	x [mm]	y [mm]	x′ [μr]	y′ [μr]
SVXII	-1.0625	1.5003	756	-314
Beam	-1.8	4.5	600	100
difference	-0.74	3.00	-156	414



The models can be used as a guide, but the errors are often larger in the “real world”

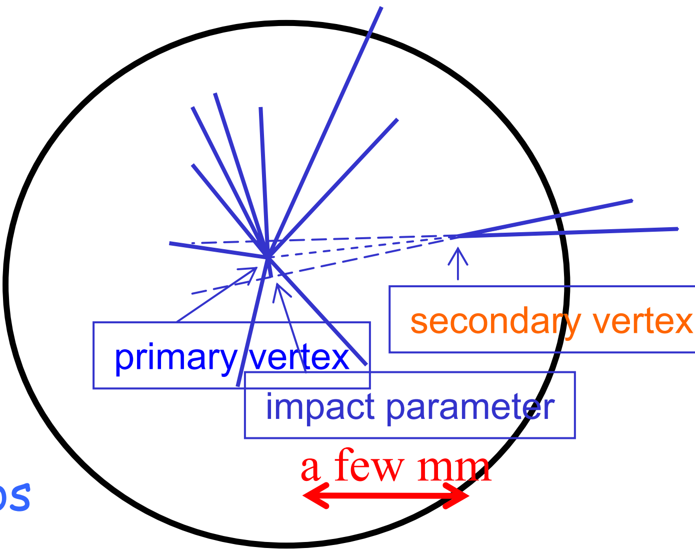
Will the CDF Silicon "Age Gracefully"?

We use simulation to study the degradation in tracking and b-tagging performance vs. integrated luminosity.

- Generate $t\bar{t} \rightarrow Wb(Wb)$ events and use CDF detector simulation
- To degrade the simulation we
  - Add shot and chip noise on all strips, according to expectations
  - Degrade resolution with noise
  - Recluster the silicon strips with new thresholds
  - Assume no trapping and full depletion
  - Remove Si layers as they 'die' from underdepletion
- Measure how often a b quark in the detector results in a 'tag'

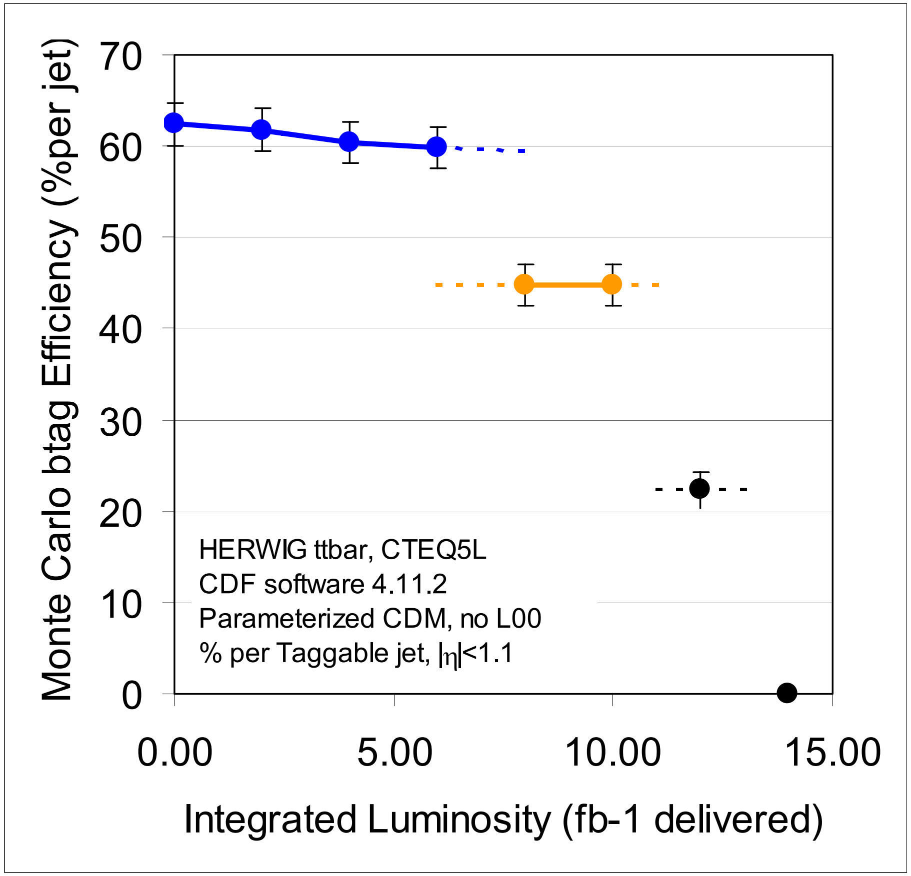
  (nb: not a quantity the physics groups usually look at)

  ε = #tagged b's / #b's
- Iterate over different radiation damage scenarios



Degradation in b-tag efficiency

(preliminary results)



- Secondary Vertex Tagging (b jets)
  - HERWIG Monte Carlo study
  - Secondary vertex (b) tagged events
  - Remove L0 from tracking at 6-8 fb^{-1} (orange points)
  - Remove L1 at 10-12 fb^{-1}
- Requirements:
  - b is in the detector ($|\eta|<1.1$)
  - b yields a jet w/ at least two tracks
- L00 not included
  - Not yet in the 'default' tracking
  - Not studied yet for tagging
- Results
  - efficiency still good after S/N degraded
  - L00 must be fully integrated and must survive to maintain tag efficiency

Conclusion

We now have Run II radiation measurements and models of S/N to compare

Assuming reasonable luminosity, we expect L0 will 'die' from underdepletion

The Run IIa silicon should continue to provide good vertex information until (at least) 6 fb^{-1}.

CDF Run IIa silicon was designed for 2 fb^{-1} and 2 years of operation…

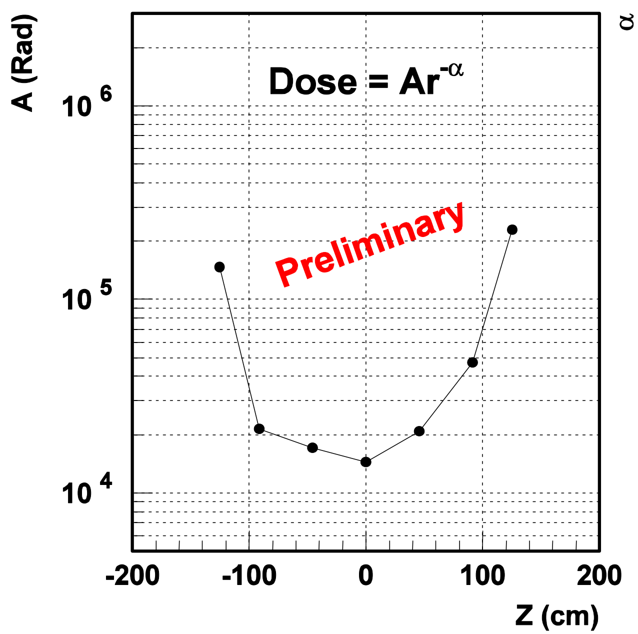
Two years done, only 6 more years to go!

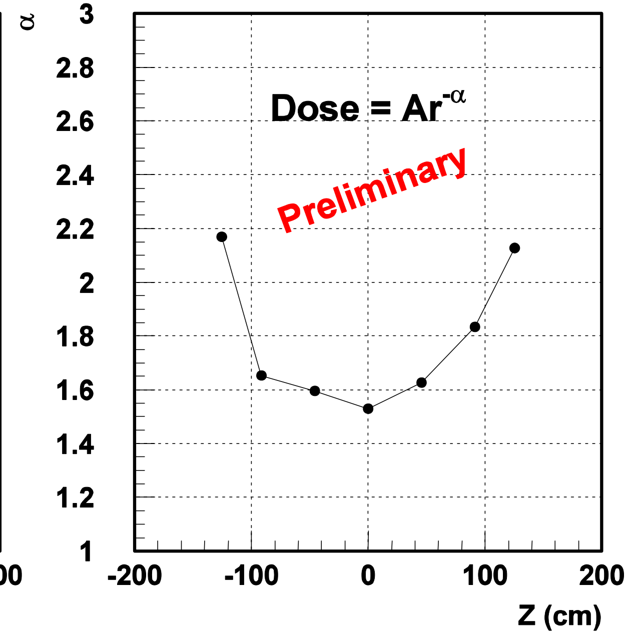
Backup - D0 vs CDF

- D0 should live to "at least 4 fb-1", CDF to 6fb-1, but…
  - D0 is ~10 °C *colder*
  - D0 inner layer is at *3cm*, CDF is at 2.5cm

- Some things to consider are…
  - Resistivity differs in inner layer (Micron vs. Hamamatsu)
    - Initial Vdep for D0 is 20-30V
    - Initial Vdep for CDF is 70-80V
  - 170V depletion for CDF without problems, less for D0
    - Microdischarge problems on one side due to alignment of implant and metal
    - Burn-in voltages lower?? (not sure…)
  - 7-8 barrel layers for CDF, much less for D0
  - Different models for Vdep

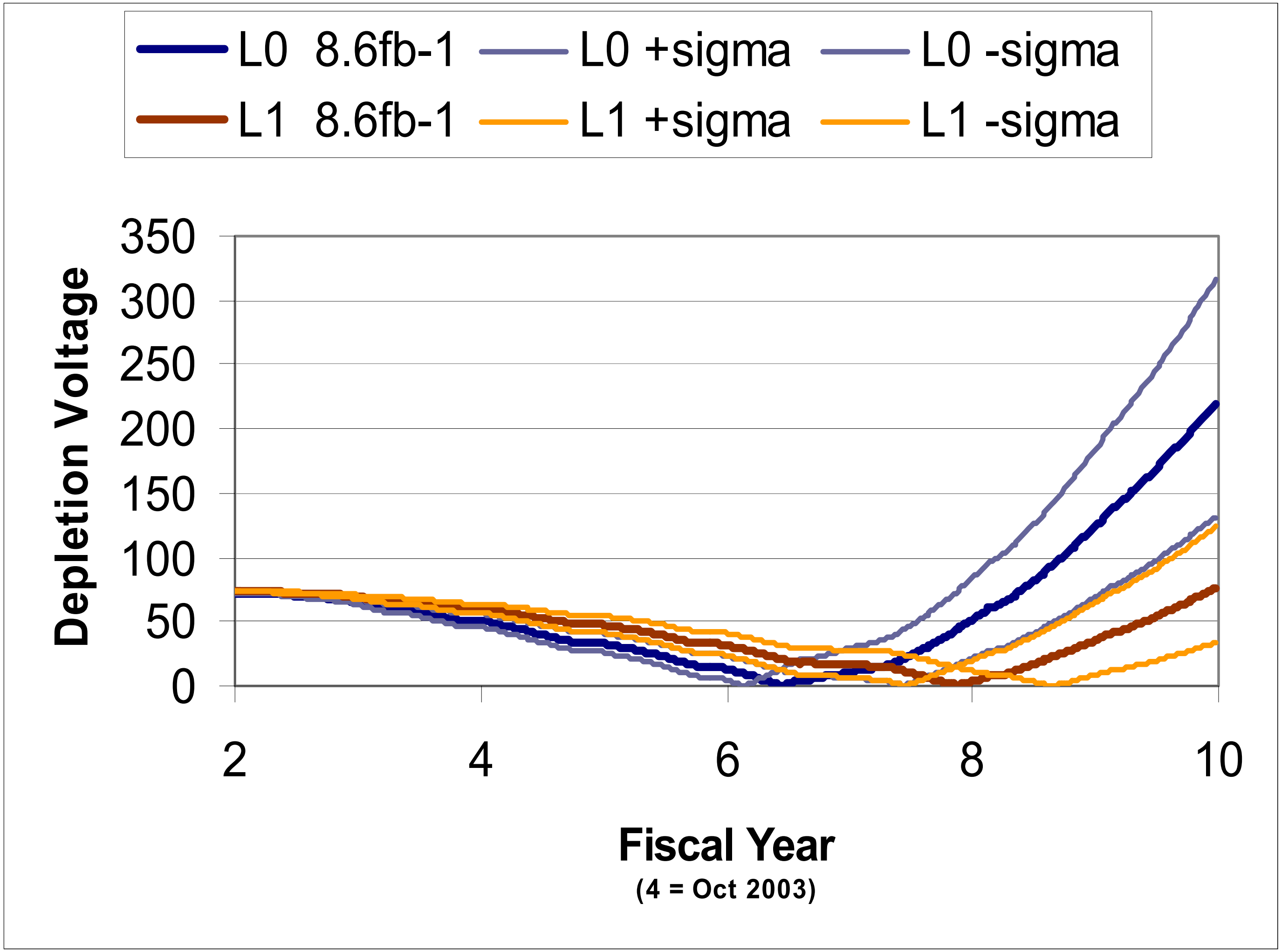
Backup - Losses/Beam Detail



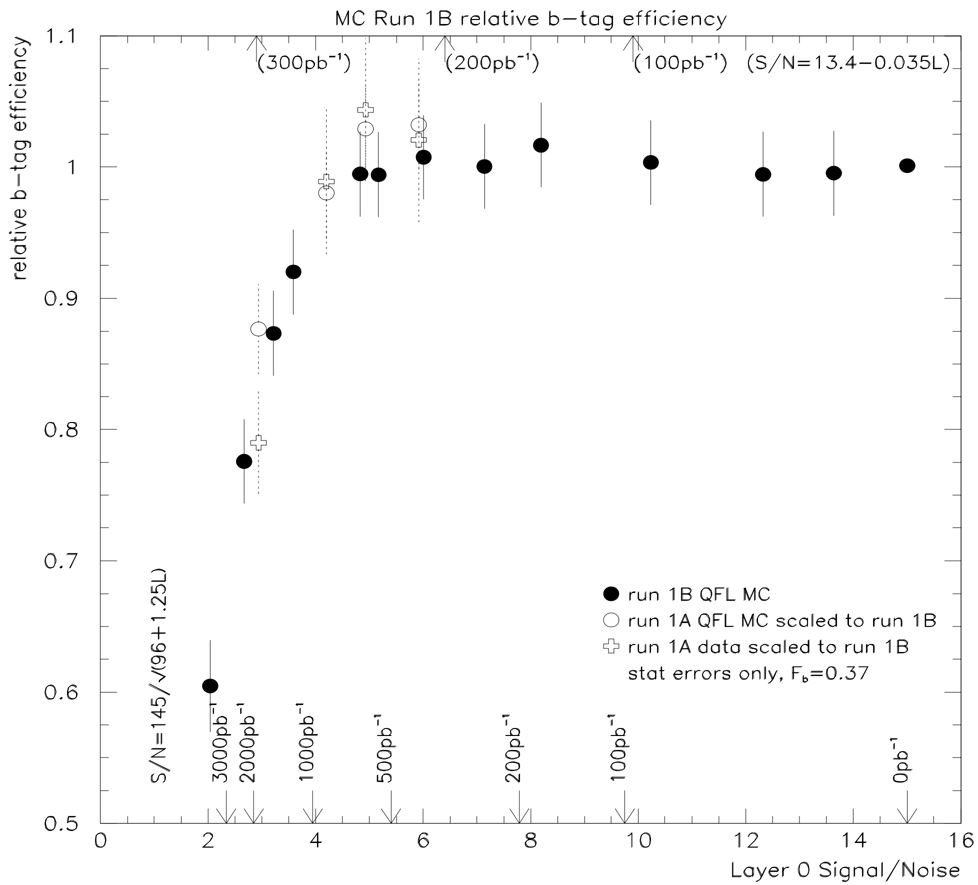


Period	Beam ($\times 10^{19}$) p	p	Losses ($\times 10^{9}$) p	p	Integrated Lum (pb^{-1})
Feb 01 - May 01	0.07	0.008	15.3	2.0	0.06
May 01 - Oct 01	1.56	0.14	40.9	10.2	10.7
Oct 01 - Jan 03	9.65	0.657	621	440	159

Backup - Vdep L1 Model



Backup - RunI b-Tag vs S/N



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Backup - Resolutions (input to Monte Carlo)

	phi-side resolutions				z-side resolutions			
layer	1-strip	2-strip	3-strip	4-strip	1-strip	2-strip	3-strip	4-strip
0	0.0011	0.0009	0.0019	0.0019	0	0	0	0
1	0.0013	0.0011	0.0023	0.0023	0.0031	0.0026	0.0054	0.0054
2	0.0013	0.0011	0.0024	0.0024	0.0027	0.0023	0.0048	0.0048
3	0.0013	0.0011	0.0023	0.0023	0.0013	0.0011	0.0023	0.0023
4	0.0013	0.0011	0.0023	0.0023	0.0031	0.0026	0.0054	0.0054
5	0.0014	0.0012	0.0025	0.0025	0.0014	0.0012	0.0025	0.0025
6	0.0024	0.0021	0.0043	0.0043	0.0024	0.0021	0.0043	0.0043
7	0.0024	0.0021	0.0043	0.0043	0.0024	0.0021	0.0043	0.0043